Non-Point Source Pollution in the Waccamaw River near the City of Conway, South Carolina: Scope of the Problem and Use of a Stormwater Best Management Practice to Achieve Load Reductions

Susan Libes, Joe Bennett, Mike Ferguson and Jeremy Saeger, Environmental Quality Lab, Center for Marine and Wetland Studies
Coastal Carolina University, Conway, SC 29526

INTRODUCTION

Kingston Lake and Crabtree Canal are tributary creeks located near the City of Conway, SC that drain into the Waccamaw River. Routine testing performed by South Carolina Department of Health and Environmental Control (SC DHEC) has demonstrated that these water bodies do not meet state water-quality standards. Because of unacceptably high levels of fecal coliform bacteria and low levels of dissolved oxygen, they have been on SC's 303(d) list since it was begun in 1996. Once SC DHEC had demonstrated a chronic problem with water quality in the Waccamaw River, the watershed became eligible for federal funds from the US EPA's Section 319 Program. Coastal Carolina University's Environmental Quality Lab was awarded over $280,000 in 1999 to undertake a very detailed and sophisticated study to determine the source and magnitude of the bacterial contamination and low dissolved oxygen in the tributary streams and the River and to conduct a pilot study to demonstrate techniques for reducing the sources of these problems.

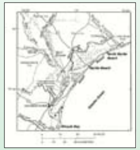


Figure 1. The Waccamaw River in South Carolina. Study site is located near the City of Conway.

STUDY DESIGN

To determine whether stormwater runoff is a significant source of pathogenic bacteria and oxygen-demanding substances in the Kingston Lake Subwatershed, pollutant concentrations and water flows were measured on alternating weeks and during five storm events throughout a two-year period (1999-2001). The sample sites, as shown on Figure 2, were located in several tributary flows (Kingston Lake Swamp, Kingston Lake Creek and Crabtree Canal) and immediately downstream in the Waccamaw River (Site 1). Kingston Lake Swamp (Site 2) drains a rural/agricultural area that extends almost to the North Carolina state line. Crabtree Canal (Site 3) is a swamp that was channelized by the US Army Corps of Engineers in the 1960s. It drains the suburban outskirts of Conway. Kingston Lake Creek (Site 4) drains part of downtown Conway and empties into Kingston Lake. Many other stormwater runoff pipes drain other sections of downtown Conway and empty directly into the Waccamaw River. By sampling at these sites, we assessed the impacts of tributary flows draining urban, suburban and rural landscapes on the River's water quality. (Water discharge and in-situ measurements of dissolved oxygen, conductivity and temperature were made by the South Carolina branch of the United States Geological Survey.)

Figure 2. Location of sampling sites in Kingston Lake Subwatershed used for US EPA 319 Program Project conducted 1999 through 2001 in the Waccamaw River and its Tributaries

BACTERIAL CONTAMINATION

Three approaches were used to determine the source of bacterial contamination. First, the concentration of another indicator species, *Enterococcus*, which is more specific than fecal coliform bacteria for human waste, was measured. Second, the magnitude of potential bacterial coliform sources was estimated from existing inventories of animals (livestock, pets, wildlife) and their average fecal production rates. Third, multiple antibiotic resistance (MAR) testing of *E. coli* (another bacterial species associated with animal wastes) was used to distinguish between wildlife, livestock, pets and human sources of bacteria. (Funding for the Multiple Antibiotic Resistance testing was provided by SC Sea Grant. Training and standardized control cultures were provided by Dr. Geoff Scott (National Oceanic and Atmospheric Administration's Center for Coastal Environmental Health & Biomolecular Research, Environmental Ecotoxicology Branch).)

All of the bacteria measured in this project grow in the intestines of animals and hence are present in their feces. If they are observed in a water sample, other more pathogenic microbes are likely present. Thus fecal coliforms, *Enteroccocci* and *E. coli* bacteria are used as presumptive indicators for the presence of fecal material and associated pathogenic microbes.

Stormwater runoff caused elevations in the levels of all three types of bacteria, plus suspended solids, oxygen-demanding substances (BOD_5), nutrients (nitrogen and phosphorus) and chlorophyll (a plant pigment used to measure algal abundance) at all the sampling sites. Concentrations exceeding state and federal water-quality criteria were frequently observed. Even during periods without rain, relatively high levels of these contaminants were observed. Lesser amounts of pollution were observed during dry weather flows, reflecting slower but chronic releases from contaminated soils, roads, roofs, agricultural fields and livestock operations. These observations suggest that nonpoint source pollution, as transported by stormwater flows, is a significant and persistent problem in the Kingston Lake Subwatershed. The impact of this pollution was not as great in the main stem of the river located immediately below the subwatershed (Site 1) due to dilution from upstream river water.

In the case of the bacteria, fecal coliform concentrations were well correlated with the two other indicator species, *E. Coli* and *Enterococcus*. This provided abundant confirmation of nonpoint pollution problems at all the sampling sites. As shown in Figure 3, frequent violations of swimming criteria were observed even in the absence of rain. Following rain events, these violations increased in frequency and intensity, with concentrations often rising over 100,000 colony forming units (CFU's) per 100 mL (Figures 4 and 5). Laboratory culture studies indicated that river water is not hospitable to these bacteria as their numbers declined below detection within two days.

The violations of bacterial water-quality criteria are observed in the absence of rain suggests a chronic source of bacteria to the River and its tributaries. One possibility is that some bacteria may settle into the sediments and form viable colonies resuspended by boat wake. A series of simulation experiments we conducted did not provide reproducible results, suggesting this is not likely to be an important contributor to chronically high levels of contaminant bacteria observed in the River and its tributaries.

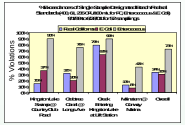


Figure 3. Percentage of times that samples, collected every other week over a 22-month period, had bacteria levels exceeding Federal Single Sample Swimming Water Criteria. Each bar represents the results of about 52 samples collected from September 1999 to August 2001.

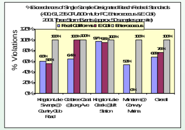


Figure 4. Percentage of times that samples, collected during three rain events in 2001, had bacteria levels exceeding Federal Single Sample Swimming Water Criteria. Each bar represents the results of about 50 samples collected from June to August 2001.

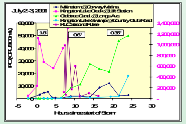


Figure 5. Fecal Coliform concentrations (colony forming units per 100 mL) in samples collected from four sites in the Kingston Lake Subwatershed during July 2 to 3, 2001, following several rain events. The quantity of rainfall and approximate timing is shown on the graph. Measurement uncertainty is ±5%. The swimming water criteria are 400 and 200 CFU/100 mL for single samples and the geometric mean of 5 samples, respectively.

The results of the multiple antibiotic resistance (MAR) testing during dry weather suggested that humans and domesticated animals were as important as wildlife in contributing to the high concentrations of contaminant bacteria observed at all the sites (Figures 6 through 11). The human sources are likely associated with broken sewer lines and leaking septic tanks. During wet weather, the relative importance of human and domesticated animal sources increased at all of the sites except for the rural Kingston Lake Swamp. This suggests that rainfall drives bacteria originating from humans and domesticated animals into the waterways (except at Kingston Lake Swamp). As more wildlife is present in the area draining into Kingston Lake Swamp, it makes sense that rainfall would drive more wildlife-derived bacteria into its receiving waters.

Figure 6. Multiple Antibiotic Resistance (MAR) Source Tracing

- 11 Antibiotics (AB) tested
- Three *E. coli* isolates per sample
- Resistant Colonies show growth on agar plates doped with antibiotics

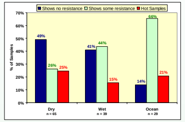


Figure 7. Results of MAR testing of *E. coli* isolated from Waccamaw River (Sites 1 through 4) and 4 sites in the Myrtle Beach area (swashes and retention ponds). Bars represent percentage of samples which demonstrated (1) No AB resistance, (2) Resistant to at least one of the AB tested, (3) resistant to several of the test AB's. Hot samples had a MAR Index >13.5%

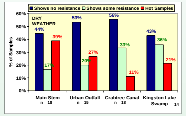


Figure 8. Results of MAR testing of *E. coli* isolated from Waccamaw River (Sites 1 through 4) sampled during dry weather.

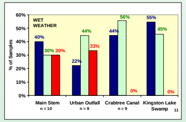
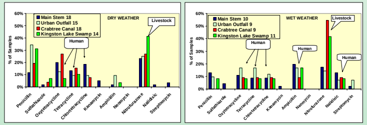


Figure 9. Results of MAR testing of *E. coli* isolated from Waccamaw River (Sites 1 through 4) sampled during wet weather.



Figures 10 and 11. Results of MAR testing of *E. coli* isolated from Waccamaw River (Sites 1 through 4) sampled during dry and wet weather. Bars represent percent of resistant isolates that were resistant to a particular AB. Source identifications were made following Parveen et al. (2000)

Estimates of fecal coliform production rates based on populations of wildlife, pets, and livestock and emissions from septic tanks and sewage treatment plants indicated that native waterfowl are the largest producers of fecal coliform in the watershed. Dogs and cats are secondary in importance. Wildlife has been observed as a significant source of contaminant bacteria in many other communities. These findings are particularly frustrating, as the sources appear to be "natural." On the other hand, these results suggest the importance of maintaining pervious surfaces in the watershed to sustain natural soil filtration and purification processes. This should also help preserve adequate habitat so that wildlife densities remain close to "natural" levels and do not overwhelm natural purification capacities. It is ironic that as we destroy wildlife habitat, we force animals to cluster in fewer and fewer remaining areas of undeveloped land, which tend to be wetlands where soils are saturated and filtration cannot provide natural removal of waste products.

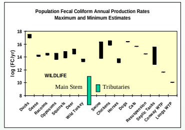


Figure 12. Estimates of Fecal Coliform Production by wildlife, domesticated animals and humans. Population estimates from SC DNR. Per capita FC production rates from ASAE (2000).

Sewage is composed of bacteria and organic wastes, so it was not surprising that elevated levels of suspended solids and oxygen-demanding substances (BOD_5) were also observed especially following rain events (Figure 13). (Some of the BOD_5 may also have been associated with eroded soils.) The relative abundance of the oxygen-demanding substances was negatively correlated with water color. This suggests that oxygen-demanding substances from nonpoint source pollution, rather than natural organic matter, are reducing dissolved oxygen levels below their naturally low levels. During the 24-hour period following a typical rain event, the amount of oxygen-demanding substances emitted via nonpoint source runoff from the tributary creeks was 9 to 18 times larger than the permitted discharge from the City of Conway's sewage treatment plant. Scaled up to an annual basis, the nonpoint source emissions are greater than 3 to 6 times the quantity permitted to the sewage treatment plant. A dissolved oxygen sag of approximately 0.5 ppm (Figure 14) was observed following storm events and is likely caused by nonpoint BOD_5 pollution. In comparison, the sewage treatment plant is not permitted to no greater than a 0.1 ppm drop in dissolved oxygen from its emissions.

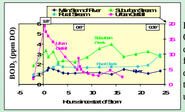


Figure 13. Five-day Biochemical Oxygen Demand in samples collected at Sites 1 through 4 following several rain events. The quantity of rainfall and approximate timing is shown. Measurement uncertainty is ±8%.

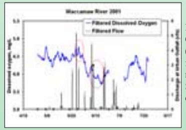


Figure 14. Dissolved Oxygen Concentration in Waccamaw River (Site 1). Concentrations have been filtered to remove effects of reversing tidal flows. Discharge at Site 2 is shown to document timing of rain events.

Nutrient levels (nitrogen and phosphorus) were not elevated to as great an extent as the other contaminants but elevated chlorophyll concentrations were observed. Chlorophyll is a green pigment produced by algae. Thus it appears that nutrients supplied by the decomposition of sewage or by fertilizer runoff were rapidly consumed by algae. This sequence of events is the beginning phase of eutrophication. Once algae or their consumers die, bacterial decomposition of their organic remains will add to the BOD_5 of the water, further lowering the dissolved oxygen levels of the water.

THE IMPORTANCE OF RETROFITTING FOR STORMWATER TREATMENT

Changes in the regulatory climate suggest that stormwater best management practices (BMPs) will soon become a standard feature of all new developments. This will enable us to minimize new sources of nonpoint source pollution. But what about existing sources – can we retrofit traditional stormwater holding ponds to help improve water quality?

Addition of constructed wetlands to these ponds could improve water quality, while enhancing the appearance of the land and maintaining flood control. To demonstrate this, we retrofitted an existing stormwater detention pond sited at Ivy Glen, a planned unit development located in Conway, SC (see Site 5 on Figure 2). This twenty-acre development will eventually contain 103 single-family homes and has five detention ponds, which outfall to a county ditch tied directly into Crabtree Canal. Our retrofit converted the largest of these (0.65 acres) from a shallow non-vegetated dry pond into an extended detention, multiple pond system as illustrated in Figure 15.

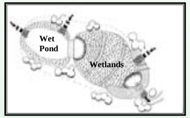


Figure 15. Schematic of Multiple Pond Stormwater Best Management Practice installed at Ivy Glen PUD. After Schueler (1999).

In this system, stormwater first enters a four-foot deep wet pond designed to promote settling of sediment. The outfall from this pond flows into a created wetland. Surface areas and volumes were designed to provide a minimum of 72 hours storage of stormwater on site for a two-year storm. Half of the surface area in the wetlands is vegetated with native species that can withstand 0 to 6 inches of standing water and the other half with species that can withstand 6 to 18 inches. The former was also used to vegetate a shallow shelf constructed around the wet pond. Shallow water depths on this shelf and in the wetlands ensure exposure of fecal coliform bacteria to destructive ultraviolet radiation and provide habitat for wetland plants. The shallow shelf is also a safety feature isolating the deep part of the pond from humans. The wetland plants enhance sediment removal through baffling. They also remove nutrients and heavy metals from the water. Microbes living in the sediment consume fecal coliform bacteria and degrade oxygen-demanding substances (BOD_5). Indigenous mosquito fish provide natural pest control.

Monitoring work conducted from 1999 to 2001, prior to the retrofit, demonstrated significant water quality impairments including elevated turbidity, chlorophyll and fecal coliform and enteroccocal bacteria levels. The construction work commenced in December 2001 and was completed in January 2002. Five-thousand indigenous wetland plants of 16 different species, provided by Mellow Marsh Farms (Pittsboro, NC), were planted in February and June 2001. Post-retrofit monitoring was conducted from May to August 2002.

During this post-retrofit monitoring, we observed that within a few days following rain events, contaminants were reduced to levels well below state and federal water-quality limits. In the case of fecal coliforms, we observed that the retrofitted BMP removed 98% of the contaminant bacteria. Removal of the other pollutants was in the range of 50%. Permanent educational signage (Figure 16) has been installed at the site explaining how the system works and is used to educate developers, property owners and municipal officials in how to employ BMPs to reduce nonpoint source pollution.

ACKNOWLEDGEMENTS

- US EPA and SC DHEC Bureau of Water
- United States Geological Survey
- SC Sea Grant
- City of Conway
- Grand Strand Water and Sewer Authority
- Castle Engineering
- Developers of Ivy Glen PUD

Figure 16. Educational Signage at Ivy Glen BMP